Effect of Maxillary Sinus Augmentation on the Survival of Endosseous Dental Implants. A Systematic Review

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Background: Grafting the floor of the maxillary sinus has become the most common surgical intervention for increasing alveolar bone height prior to the placement of endosseous dental implants in the posterior maxilla. Outcomes of this procedure may be affected by specific surgical techniques, simultaneous versus delayed implant placement, use of barrier membranes over the lateral window, selection of graft material, and the surface characteristics and the length and width of the implants.

Rationale: The primary objective of this systematic review was to determine the efficacy of the sinus augmentation procedure and compare the results achieved with various surgical techniques, grafting materials, and implants.

Focused Question: In patients requiring dental implant placement, what is the effect on implant survival of maxillary sinus augmentation versus implant placement in the non-grafted posterior maxilla?

Search Protocol: MEDLINE, the Cochrane Oral Health Group Specialized Trials Register, and the Database of Abstracts and Reviews of Effectiveness were searched for articles published through April 2003. Hand searches were performed on *Clinical Oral Implants Research, International Journal of Oral and Maxillofacial Implants*, and the *International Journal of Periodontics & Restorative Dentistry* and the bibliographies of all relevant papers and review articles. In addition, researchers, journal editors, and industry sources were contacted to see if pertinent unpublished data that had been accepted for publication were available.

Selection Criteria

Inclusion criteria: Human studies with a minimum of 20 interventions, a minimum follow-up period of 1-year loading, an outcome measurement of implant survival, and published in English, regardless of the evidence level, were considered.

Exclusion criteria: Studies involving multiple simultaneous interventions (e.g., simultaneous ridge augmentation) and studies with missing data that could not be supplied by the study authors were excluded.

Data Collection and Analysis: Where adequate data were available, subgroups of dissimilar interventions (e.g., surgical techniques, graft materials, implant surfaces, membranes) were isolated and subjected to meta-regression, a form of meta-analysis.

Main Results

1. Forty-three studies, 3 randomized controlled clinical trials (RCTs), 5 controlled trials (CTs), 12 case series (CS), and 23 retrospective analyses (RA) were identified. Thirty-four were lateral window interventions, 5 were osteotome interventions, 2 were localized management of the sinus floor, and 2 involved the crestal core technique.

2. Meta-regression was performed to determine the effect of the variables of block versus particulate grafting techniques, implant surface, graft material, and the use of a membrane over the lateral window.

3. The survival rate of implants placed in sinuses augmented with the lateral window technique varied between 61.7% and 100%, with an average survival rate of 91.8%.

For lateral window technique:

4. Implant survival rates reported in this systematic review compare favorably to reported survival rates for implants placed in the non-grafted posterior maxilla.

5. Rough-surfaced implants have a higher survival rate than machine-surfaced implants when placed in grafted sinuses.

6. Implants placed in sinuses augmented with particulate grafts show a higher survival rate than those placed in sinuses augmented with block grafts.

7. Implant survival rates were higher when a membrane was placed over the lateral window.

8. The utilization of grafts consisting of 100% autogenous bone or the inclusion of autogenous bone as a component of a composite graft did not affect implant survival.

9. There was no statistical difference between the covariates of simultaneous versus delayed implant placement, types of rough-surfaced implants, length of follow-up, year of publication, and the evidence level of the study.

Reviewers' Conclusions: Insufficient data were present to statistically evaluate the effects of smoking, residual crestal bone height, screw versus press-fit implant design, or the effect of implant surface micromorphology other than machined versus rough surfaces.

There are insufficient data to recommend the use of platelet-rich plasma in sinus graft surgery.
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KEY WORDS

Inadequate alveolar bone height is a common limitation in the placement of endosseous root-form dental implants in the posterior maxilla. Grafting the floor of the maxillary sinus has emerged as the most common surgical modality for correcting this inadequacy. This technique, first published in 1980 by Boyne and James[1] and subsequently modified by other clinicians,[2-10] can result in an increase in bone height that allows the placement of implants of conventional length in the grafted sites.

In addition to the various techniques utilized to elevate the sinus floor, there are many variables that may alter the outcome of this procedure. Among them are simultaneous versus delayed implant placement; the use of a barrier membrane over the lateral window; the use of various grafting materials; and the utilization of implants with varying surface characteristics, lengths, and widths. Further, the effects of smoking and residual crestal bone height may also influence outcomes.

The goal of this review was to assess the efficacy of the sinus augmentation procedure by systematically reviewing the available literature.

RATIONALE

The goal of this review was to assess the efficacy of the sinus augmentation procedure by systematically reviewing the available literature.

FOCUSED QUESTION

This review address the following question: "In patients requiring dental implant placement, what is the effect on implant survival of maxillary sinus augmentation versus implant placement in the non-grafted posterior maxilla?"

SEARCH PROTOCOL

Data Sources and Search Strategy

The search protocol chosen by the authors utilized 3 electronic databases: MEDLINE from 1980 through April 2002 utilizing the Ovid search engine; the Cochrane Oral Health Group Specialized Trials Register through April 2002; and the Database of Abstracts of Reviews of Effectiveness through April 2002. The search strategy for electronic databases utilized a combination of MeSH terms and text words to create both a specific (human, English, randomized controlled trials, and meta-analysis) and a sensitive database. The search strategy and results utilized for MEDLINE are shown in Table 1.

The search was supplemented by a thorough manual search of the following journals: *Clinical Oral Implants Research, International Journal of Oral and Maxillofacial Implants*, and *International Journal of Periodontics & Restorative Dentistry* from 1980 or journal inception through the cut-off date of April 1, 2002, along with a search of the bibliographies of all relevant papers and review articles.

As part of the review process, researchers were contacted when possible to fill in missing data or clarify ambiguous data in previously published reports. Known researchers, journal editors, and industry sources were contacted to determine if pertinent unpublished data that had been accepted for publication were available. All search strategies were updated to extend the cut-off date to April 1, 2003. Both the titles and abstracts from the search were independently screened for inclusion by the review authors. The full text of all studies of possible relevance were obtained and independently reviewed by the review authors (SSW, SJF). Disagreements at each level of the review process were resolved by discussion.

Inclusion criteria: All studies involving the placement of root-form screw or cylinder implants in augmented maxillary sinuses were considered. An outcome measure of implant success or implant survival had to be reported. As the number of randomized controlled clinical trials (RCTs) was found to be limited, all levels of evidence including controlled trials (CT), case series (CS), and retrospective analyses (RA) were selected for further evaluation by the inclusion criteria.

The original inclusion criteria for this review were as follows: 1) human, English language publications; 2) minimum of 20 interventions (i.e., lateral window sinus augmentations or osteotome elevations); 3) outcome measure of implant success or implant survival reported; 4) absence of multiple interventions (e.g., simultaneous ridge augmentations); 5) minimum of 1-year loaded follow-up (or a range that exceeds 1 year); and 6) a dropout/withdrawal rate of ≤5%.

Exclusion criteria: Studies involving multiple interventions (e.g., simultaneous ridge augmentation) and

Table 1.

MEDLINE Search Terms and Results

1. exp Dental Implants/	4,846
2. exp Dental Implantation/	9,317
3. 1 or 2	11,379
4. exp Bone Transplantation/	13,455
5. exp Bone Remodeling/	25,098
6. 4 or 5	36,692
7. exp Maxillary Sinus	5,180
8. exp Maxilla/	11,893
9. 7 or 8	16,781
10. 6 and 9	1,478
11. exp Alveolar Ridge Augmentation/	1,226
12. 10 or 11	2,483
13. 12 and 3	1,037
14. maxillary sinus grafting.mp.	10
15. sinus augmentation.mp.	69
16. sinus lift.mp.	79
17. sinus elevation.mp.	38
18. 14 or 15 or 16 or 17	170
19. 12 or 18	2,516
20. 19 and 3	1,058
21. limit 20 to (human and English language)	858
22. from 21 keep 1-858	858
23. limit 3 to (human and English language and meta-analysis or randomized controlled trial)	119
24. limit 19 to (human and English language and meta-analysis or randomized controlled trial)	24
25. limit 20 to (human and English language and meta-analysis or randomized controlled trial)	18

studies with missing data that could not be supplied by the study authors were excluded.

Ranking of Studies

Study quality was independently assessed by the reviewers and the studies grouped by general category (RCT, CT, CS, and RA).

Data Collection and Analysis

Multiple confounding relationships may result in significant differences in the outcome measurement of implant survival. Where adequate data existed, subgroups of dissimilar interventions (e.g., surgical technique, graft material) were isolated and subjected to meta-regression, a form of meta-analysis, to identify them as possible sources of covariance.

Data sheets were prepared to extract all data of possible relevance for statistical analysis of study variables. The extraction was performed independently by both reviewers to insure accuracy. Missing data were filled in, when possible, by correspondence with the study authors.

MAIN RESULTS

Methodological Quality

Overall study quality was deemed poor, with RCTs and CTs accounting for only 18.6% of the included studies (8 of 43). With modification of the inclusion criteria agreed upon early in the process, initial agreement between the reviewers was high with all disagreements resolved after discussion (6 studies) or the procurement of additional data from the study authors (6 studies). Rating of the included studies by defined criteria such as those of Jadad et al.[11] based upon criteria including randomization, masking, and withdrawals (loss to follow-up) was not practical. Since loss to follow-up was unrecorded or unclear in 18 of the 43 studies (41.9%), this requirement was eliminated from the inclusion criteria of this review. Thirty-two out of the 43 studies (74.4%) used implant survival as the primary outcome measure. Among those that reported implant success, the criteria for success varied greatly. Therefore, implant survival (i.e., implant remains in function, no pain or mobility, no radiographic evidence of infection) was chosen as the default outcome, even if both values were given. Furthermore, in many studies implant survival was not reported for a standard time interval, but was reported as a range. This was accepted, with a minimum of 12 months of loading considered for inclusion in this review.

Data Extraction

The search strategy revealed 893 (858 electronic search, 35 manual search) articles of possible relevance. One hundred and fifty-six (156) of these articles were evaluated in full-text version and 43 met the modified inclusion criteria. Of these, 34[12-45] utilized lateral window interventions, 5 utilized the osteotome technique,[46-50] 2 utilized localized management of the sinus floor (LMSF),[51,52] and 2 utilized crestal core elevation techniques.[53,54] The number of qualifying studies of each study design (RCT, CT, CS, or RA) for each of the 4 interventions (lateral window, osteotome, localized management of the sinus floor, and crestal core elevation) are shown in Tables 2 through 5. The combined raw implant data for each intervention, and the overall combined implant data are listed in Table 6.

Table 2.

Summary of Data from Lateral Window Sinus Augmentation Studies

Reference	Study Type	Placement	Implant	Membrane	Graft Material	N Lifts	N Implants	N Survived	N Failed	% Survived
Boyne et al.[12] 2003	RCT	Delayed	Various	None	Autog autog + allo	24	63	51	12	81
Boyne et al.[12] 2003	RCT	Delayed	Various	None	BMP-2/collagen sponge	64	156	131	25	83
Tarnow et al.[13] 2000	RCT	Delayed	Various	ePTFE or none	Various	24	55	53	2	96.4
Wannfors et al.[14] 2000	RCT	Immediate/ delayed	Machined screw	None	Iliac block vs. particulate	80	150	126	24	84
Tawil & Mawla[15] 2001	CT	Immediate/ delayed	Machined screw	Por coll or none	BPBM 100%	30	61	52	9	85.2
Froum et al.[16] 1998	CT	Immediate/ delayed	Various screws	Various or none	Xenograft with or without DFDBA/ autog	113	215	211	4	98.2
Blomqvist et al.[17] 1998	CT	Delayed	Machined screw	None	Iliac block + cancellous chips	100	202	170	32	84.2
Valentini & Abensur[18] 1997	CS	Immediate/ delayed	52 cylinder; 8 screw	None	BPBM + DFDBA 1:1	28	60	56	4	93.3
Engelke et al.[19] 2003	CS	Immediate/ delayed	Various titanium	None	TCP, TCP + autog	118	211	200	11	94.8
Hallman et al.[20] 2002	CT	Delayed	Machined screw	None	Chin:BPBM (1:4)	30	79	73	6	92.4
Hallman et al.[21] 2002	CS	Delayed	Machined screw	None	Various	36	111	101	10	91
Kahnberg et al.[22] 2001	CS	Immediate	Machined screw	None	Iliac block + cancellous chips	39	91	56	35	61.2
Valentini et al.[23] 2000	CS	Delayed	Not specified	None	BPBM	20	57	56	1	98.2
van den Bergh et al.[24] 2000	CS	Delayed	Screw	None	DFDBA	30	69	69	0	100
van den Bergh et al.[25] 1998	CS	Immediate/ delayed	Screw	None	Iliac cancellous bone chips	62	161	161	0	100
Peleg et al.[26] 1998	CS	Immediate	HA cylinder	DLB	1:1 iliac + DFDBA	20	55	55	0	100
Block & Kent[27] 1995	CS	Immediate/ delayed	HA cylinder and screw	None	various autog & autog composites	51	173	171	2	98.9
Keller et al.[28] 1994	CS	Immediate	Not specified	None	Iliac block	23	66	60	6	90

Table 2. (continued)

Summary of Data from Lateral Window Sinus Augmentation Studies

Reference	Study Type	Placement	Implant	Membrane	Graft Material	N Lifts	N Implants	N Survived	N Failed	% Survived
Lozada et al.[29] 1993	CS	Immediate/ delayed	Various	None	Various composites	69	158	145	13	92
Rodriguez et al.[30] 2003	RA	Immediate	Various	None	BPBM + PRP	24	70	65	5	92.9
Hising et al.[31] 2001	RA	Delayed	Various; 88% machined	None	BPBM, BPBM + symphysis	36	104	86	18	82.7
Lorenzoni et al.[32] 2000	RA	Immediate/ delayed	Screw	Various	BPBM or autogenous bone	42	98	92	6	92.7
Johansson et al.[33] 1999	RA	Immediate	Machined screw	None	Iliac & mandibular block	39+	131	100	31	75.3
Keller et al.[34] 1999	RA	Immediate	Machined screw	None	Iliac block	58	139	119	20	85.6
Khoury[35] 1994	RA	Immediate	Various	ePTFE or none	Mandibular block + particulate	216	467	439	28	94
Peleg et al.[36]	RA	Immediate	HA cylinder	DLB	1:1 symphysis + DFDBA	63	160	160	0	100
Watzek et al.[37]	RA	Delayed	Cylinder and Screw	None	cancellous iliac, iliac + BPBM or Int-200	40	145	139	6	95.9
Kaptein et al.[38] 1998	RA	Immediate/ delayed	HA cylinder	None	2:1 iliac cancellous + non-resorbable HA	>88	388	342	46	88.1
Fugazzotto & Vlassis[39] 1998	RA	Immediate/ delayed	TPS cylinder	None	Various non-autogenous	217	510	495	15	97
Ellegard et al.[40] 1997	RA	Immediate	Screw	None	None	24+	38	35	3	92.1
Block & Kent[41] 1997	RA	Immediate	Not specified	None	Iliac/tibial marrow, intraoral	53	173	153	20	88.4
Hürzeler et al.[42] 1996	RA	Immediate/ delayed		ePTFE	Various	168	340	336	4	98.8
Wheeler et al.[43] 1996	RA	Immediate/ delayed	54 cylinder; 6 machined screw	None	HA, HA + iliac, HA + intraoral	34	64	61	3	95.3
Blomqvist et al.[44] 1996	RA	Immediate	Machined screw	None	Iliac block	93	171	141	30	82.5
Small et al.[45] 1993	RA	Immediate	TPS, HA cylinder	Collagen	DFDBA & HA	20+	76	76	0	100

Abbreviations: auto = autogenous; allog = allograft; BPBM = bovine porous bone mineral; BMP = bone morphogenetic proteins; DFDBA = demineralized freeze-dried bone allograft; DLB = demineralized laminar bone; ePTFE = expanded polytetrafluoroethylene; HA = hydroxyapatite; por coll = porcine collagen; PRP = platelet-rich plasma; TCP = tricalcium phosphate; TPS = titanium-sprayed surface.

Table 3.

Summary of Data from Osteotome Sinus Augmentation Studies

Reference	Study Type	Placement	Implant	Graft Material	N Lifts	N Implants	N Survived	N Failed	% Withdrawn	% Survived
Zitzmann & Schärer[46] 1998	CT	Immediate	Machined screw	BPBM	59	59	56	3	0	94.9
Deporter et al.[47] 2000	CT	Immediate	Rough surface cylinder	BPBM	26	26	26	0	0	100
Rosen et al.[48] 1998	RA	Immediate	Various	Various	174	174	166	8	*	95.4
Coatoam & Krieger[49] 1997	RA	Immediate	4, mostly rough cylinder	DFDBA + minimum auto	89	89	82	7	0	92.1
Cavicchia et al.[50] 2001	RA	Immediate	Cylinder and screw	collagen sponge auto	97	97	86	11	0	88.6

* Not reported.
Abbreviations: BPBM = bovine porous bone mineral; auto = autogenous; DFDBA = demineralized freeze-dried bone allograft.

Table 4.

Summary of Data from Localized Management of Sinus Floor Studies

Reference	Study Type	Placement	Implant Type	Graft Material	N Lifts	N Implant	N Survived	N Failed	% Withdrawn	% Survived
Bruschi et al.[51] 1998	RA	Immediate	Cylinder and screw	Collagen sheet	499	499	487	12	*	97.5
Winter et al.[52] 2002	RA	Immediate	Screen	None	58	58	53	5	0	91.4

* Not reported.

Table 5.

Summary of Data from Crestal Core Elevation Studies

Reference	Study Type	Placement	Implant Type	Graft Material	N Lifts	N Implants	N Survived	N Failed	% Withdrawn	% Survived
Toffler[53] 2001	RA	Delayed	Various	Auto + BPBM or P-15	37	37	37	0	0%	100
Fugazzotto & De Paoli[54] 2002	RA	Delayed	Screw	BPBM	137	137	134	3	*	97.8

* Not reported.
Abbreviations: auto = autogenous; BPBM: bovine porous bone mineral; P-15 = peptide 15.

Table 6.

Combined Sinus Implant Data for all Interventions

Intervention	N Lifts	N Implants	N Survived	N Failed	% Survived
Lateral window (34)	2,178	5,267	4,836	431	91.8
Osteotome (5)	445	445	416	29	93.5
Localized management of sinus floor (2)	557	557	540	17	96.9
Crestal (2)	174	174	171	3	98.3
Total	3,354	6,443	5,963	480	92.6

Table 7.

Survival Rates for Rough Versus Machined Implants

Surface	Standard Error	Mean	Least Square Mean*
Machined	1.98	82.4	84.0
Rough	2.82	95.2	91.6

* Includes adjustments for other variables.

Table 8.

Survival Rates for Implants Placed in Iliac Blocks Versus Particulate Grafts

Graft	Standard Error	Mean	Least Square Mean*
Iliac block	2.96	80.4	83.3
Particulate	1.72	94.8	92.3

* Includes adjustments for other variables.

Table 9.

Interaction of Covariates Machined/Rough, Iliac Block/Particulate

Surface/Intervention	N Studies	Lower 95% CI	Upper 95% CI	Standard Error	Mean	Least Square Mean*
Machined/iliac block	6	73.8	83.8	2.5	78.8	78.8
Machined/particulate	3	83.4	96.6	3.3	89.5	90.0
Rough/iliac block	1	–	–	6.1	90.9	89.5
Rough/particulate	24	92.2	97.0	1.2	94.5	94.6

* Includes adjustment for other variables.

Statistical Analysis

Statistical analysis was utilized to determine what factors may have influenced the survival rate of the implants placed in the grafted sinuses. Factors evaluated included the secondary outcome measures of various surgical techniques, grafting materials, implant surface micromorphology, presence of a barrier membrane over the window, simultaneous versus delayed implant placement, and length of follow-up.

The following 3 factors were found to be related to implant survival: 1) machined implants versus rough implants (84.0% and 91.6%, respectively) (Table 7); 2) iliac block grafts versus particulate grafts (83.3% and 92.3%, respectively) (Table 8); the above-mentioned effects with the appropriate interaction between the 2 were modeled along with the covariates of year published and the length of follow-up (Table 9); 3) membrane versus no membrane over lateral window (93.6% and 88.7%, respectively).

Table 10 identifies 3 studies[13,15,16] that directly compared implant survival following use or non-use of a membrane. In each of the 3 studies, implant survival was significantly higher when a membrane was utilized. Figure 1 presents a meta-analysis of the data from the 3 above-mentioned studies. Table 11 gives implant survival statistics for all studies utilizing particulate grafting techniques with (5 studies) and without (15 studies) a membrane over the lateral window.

As can be seen in Table 12, statistical evaluation did not indicate a difference between simultaneous versus delayed placement.

Additionally, implant type (except machined), autogenous (particulate) versus bone replacement grafts, evidence level of study, length of follow-up, and year of publication were not related to implant survival. While we tested and did not find differences between the studies for the above factors, it is possible that other factors (e.g., residual crestal bone height, smoking) could be covariables that influenced these results. There were insufficient data available to evaluate the effects of residual crestal bone height and the effect of smoking on the survival of implants placed in augmented sinuses.

DISCUSSION

The goals of the sinus elevation procedure are 3-fold: the formation of vital bone in the pneumatized sinus, inte-

Table 10.

Membrane Versus No Membrane (intra-study comparison): Implant Survival Data

Reference	With Membrane	Without Membrane
Tarnow, et al[13] (RCT)	28 implants 100%	27 implants 92.6%
Tawil & Mawla[15] (CT)	29 implants 93.1	32 implants 78.1%
Froum, et al[16] (CT)	133 implants 99.2%	82 implants 96.3%

gration of implants in that bone, and long-term survival of those implants when placed under functional load. Since the first publication of this technique by Boyne and James[1] in 1980 there have been many changes in implant surfaces, grafting materials, and surgical techniques. This report utilized an evidence-based review of the literature (893 studies) to establish a reliable database (43 studies) that satisfied the selected inclusion criteria. These data were subjected to meta-regression, a form of meta-analysis, to answer the primary question relating to overall implant survival. Secondary questions relating to various surgical techniques, grafting materials, and implant surfaces were also subjected to comparison by meta-regression to determine if these potentially confounding relationships resulted in significant statistical differences.

Methodological Quality

Any discussion of the data presented in this systematic review must be preceded by a discussion of the methodological quality of the studies that comprise the data for the review. Study quality was deemed poor. Only 8 of 43 studies were randomized controlled clinical trials or controlled trials and, with the exception of 2 studies,[12,14] investigative rigor was deemed fair to poor. Randomized controlled human clinical trials, utilizing a split-mouth design, that compare the survival of implants placed in grafted sinuses to that of implants placed below the sinus floor in the non-grafted posterior maxilla, would be difficult to conduct and to date data of this kind do not exist. For this reason intra-study comparisons of implant placements in grafted sinuses to implants placed in the non-grafted posterior maxilla were not possible. Furthermore, there is a paucity of published data reporting on aborted or failed sinus grafting procedures that precluded implant placement. This would not result in a change in the implant survival rate of placed implants, but it must be accounted for in a comparison of patient outcomes. The effectiveness of meta-analysis is dependent not only upon the quality of the included studies, but their similarity. Meta-analysis generally involves studies that are comparative in nature and is strongest when the level of evidence includes high quality RCTs. Evaluation of data from multiple studies that are one-group designs requires meta-regression. Dissimilar inter-ventions (surgical techniques), variable graft maturation and osseointegration times, varying follow-up times, differing criteria for success, the utilization of multiple grafting materials, and diverse implant macro- and micromorphologies can effect the validity of the analysis. For that reason, the present review attempted to isolate some of the significant variables to determine their effect on the overall database. Meta-regression evaluates the many covariates that exist between studies to try to insure that differences in results are, in fact, real effects.[55]

In 1998 Jensen et al.[56] published the data from the Academy of Osseointegration Sinus Consensus Conference of 1996. This report included a meta-analysis of the data collected from 38 surgeons who performed 1,007 sinus grafts with 2,997 implants placed and followed for a minimum of 3 years. The overall survival rate was reported as 90%. This report is not included in the present review as it contains data from both published and unpublished sources. Furthermore, the data from that conference would represent a duplication of some of the studies included in this review.

Previous evidence-based reviews of the maxillary sinus augmentation procedure have been published by Tolman[57] and Tong et al.[58]

Tolman[57] selected 58 of 352 screened articles for inclusion in a meta-analysis of varying grafting proce-

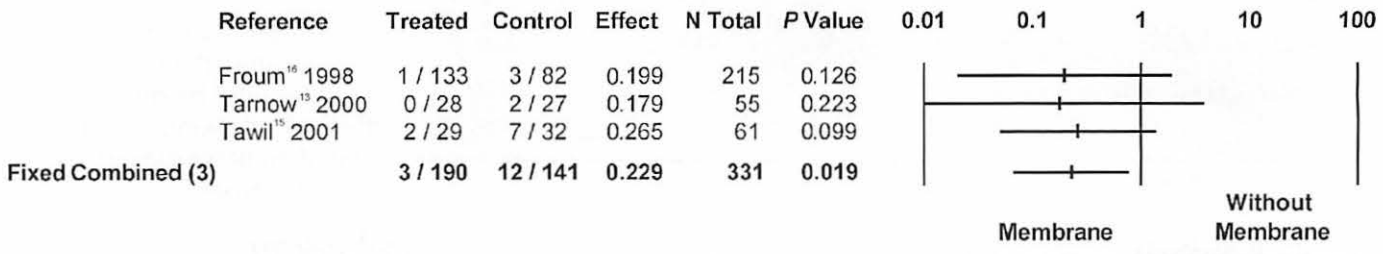

Figure 1.
Effect of the use of a barrier membrane.

Table 11.

Membrane Versus No Membrane: Implant Survival Data

Membrane	Reference	Standard Error	Mean	Least Square Mean*
No; 15 studies	14, 18, 20, 21, 23, 25, 27, 29 33, 37, 38, 39, 40, 41, 43	2.37	93.5	88.7
Yes; 5 studies	26, 32, 36, 42, 45	3.13	98.6	93.6

* Includes adjustment for other variables.

Table 12.

Simultaneous Versus Delayed Placement: Summary of Implant Data

Placement	N Studies	N Implants	N Survived	N Failed	% Survived
Simultaneous (all)	12	1,637	1,459	178	89.1
Delayed (all)	9	1,041	929	112	89.2
Simultaneous (mixed)	8	547	499	48	91.2
Delayed (mixed)	8	655	591	64	90.2
Total simultaneous	20	2,184	1,958	226	89.7
Total delayed	17	1,696	1,520	176	89.6

dures in the mandible and maxilla. Inclusion criteria were not specifically stated. Included studies were those that were clinically related with data on implants placed in grafted bone. Overall survival rates for implants placed in grafted sinuses were reported as 91% for implants placed in block grafts and 94% for implants placed in particulate grafts. Survival rates were lower for delayed placements than for immediate placements in both the block graft group (84% and 92%, respectively) and the particulate graft group (91% and 100%, respectively). A disproportionate number of the failures in the delayed particulate group (301 implants) involved a small number of machined implants (12 of 35 implants). In the delayed block graft group (61 implants), a small number of TPS cylinder implants accounted for the higher failure rate (8 of 24 implants).

Tong et al.[58] selected 10 of 28 identified articles for inclusion in their meta-analysis. Inclusion criteria were 1) at least 10 patients; 2) all patients received root-form endosseous implants; 3) less than 5% of patients were lost to follow-up over a 6-month period; 4) patient follow-up was no less than 6 months; and 5) data regarding survival of implants were reported. The overall survival rate for the 1,096 implants included was 93%.[58] An independent evidence-based review on the lateral window technique by Del Fabbro et al.,[59] submitted concurrently with the present review, selected 39 studies for inclusion. Of these, 29 were included in the present review along with 5 studies which they did not consider. The overall implant survival rate for the 6,990 implants included in their review was 91.3%.

The inclusion criteria for the present review, while far from rigorous, appear to be more selective than those utilized in the previous reviews. Furthermore, they were designed so as not to exclude earlier studies that tended to be retrospective nature, yet may not have been as susceptible to publication bias as the more recent studies. As techniques become more universally applied, the overall quality of studies tends to improve.

The present review reports on 3,354 interventions and 6,443 placed implants with an overall survival rate of 92.6%. In studies that utilized only the lateral window technique, the reported survival rate for 2,178 interventions with 5,267 implants placed was 91.8%. The database for this review is larger than that of the 3 previously mentioned reviews combined[56-58] and somewhat smaller than the Del Fabbro et al. review[59] with regard to lateral window placements. This reflects the recent increase in studies relating to sinus grafting after the 1996 Academy of Osseointegration Sinus Consensus Conference concluded "The sinus graft should now be considered a highly predictable and effective therapeutic modality."[56]

Although the large number of interventions included in this review may be the result of liberal inclusion criteria that accepted respective studies, all the studies included for analysis do have the minimum 1-year loaded follow-up.

The survival rate for implants placed in grafted sinuses compares favorably to those generally reported for implants placed in pristine bone in the non-grafted posterior maxilla.[60-67] Results from 8 studies that isolate success/survival data for implant placement in the non-grafted posterior maxilla, adjusted to raw survival data, appear in Table 13. The survival rate averaged 95.1%. Results of a 3-year Veterans Administration study reported a 97.5% survival rate for 120 implants placed in grafted sinuses compared to a 90.3% survival rate for 453 implants placed in the non-grafted posterior maxilla in a conventional manner.[64] It should be

Table 13.

Survival Rates of Conventionally Placed Implants in the Posterior Maxilla

Reference	Implant Type	N Implants			% Survived
		Placed	Survived	Failed	
Nevins and Langer[60] 1993	Screw	652	621	31	95.2
Bahat[61] 1993	Screw	732	697	35	95.2
Buser et al.[62] 2000	ITI	298	293	5	98.3
Bahat[63] 2000	Screw	660	625	35	94.7
Olson et al.[64] 2000	Various	453	409	44	90.3
DePorter et al.[65] 2001	Rough surface cylinder	118	116	2	98.3
Testori et al.[66] 2001	Screw	184	181	3	98.4
Testori et al.[67] 2002	Screw	123	121	2	98.4
Total		3,220	3,063	157	95.1

noted that none of these studies presented a split-mouth randomly controlled methodology.

The present review further identified 3 interventions that were not included in the 2 earlier reviews. The osteotome technique (5 studies,[46-50] 445 implants, and 93.5% survival), localized management of the sinus floor (2 studies,[51,52] 557 implants, 96.9% survival) and the crestal core elevation/extraction socket technique (2 studies,[53,54] 174 implants, 98.3% survival). While these results appear promising, the data are insufficient for statistical analysis.

Grafting Materials

The Academy of Osseointegration Sinus Consensus Conference of 1996 approved autogenous bone as acceptable for sinus grafting, further stating that other grafting materials (i.e., allografts, xenografts, and alloplasts) may be acceptable, but required further evaluation.[56] That evaluation has been forthcoming over the past 7 years.

The present review found that the block grafting technique results in a statistically significant lower implant survival rate (83.3%) than do all particulate grafts combined (92.3%). The lower survival rate may be indicative of a more demanding surgical procedure which requires stabilization of the block graft as well as the implant, the tendency of the iliac block graft to resorb and the covariable effect of the use of machine-surfaced implants in 6 of the 7 block graft studies.[14,17,22,33,34,44] The review by Del Fabbro et al.[59] noted that 69.5% of all implants placed in 100% autogenous bone grafts had a machined surface. These machined implants accounted for 87.8% of the failures in that group. The present review identified one well conducted RCT by Wannfors et al.[14] that compared simultaneous placement of implants in iliac block grafts to delayed placement in autogenous particulate grafts. The study included 20 patients in each group and an almost identical number of implants (76 and 74, respectively). Survival rates for implants placed in the iliac blocks and the particulate grafts were 78.9% and 89.2%, respectively. The authors stated that the population was too small to ascribe statistical significance to the results; however, they noted that their preference is now the 2-stage procedure.

This review found no statistically significant difference in implant survival when comparing particulate autogenous bone with particulate bone replacement grafts. Froum et al.[16] demonstrated similar implant survival rates for a xenograft* when utilized with or without autogenous bone. Hising et al.[31] reported a higher implant survival rate in cases where a xenograft† was used as the sole graft material (92.2%) than when it was used as a composite with autogenous bone (77.2%). In a study by Hallman et al.[21] the implant survival rates for sinuses grafted with particulated ramus autograft, a 20/80 autogenous/xenograft† composite, and 100% xenograft† were 82.4%, 94.4%, and 96%, respectively.

A review assessing the value of anorganic bone additives by Merkx et al.[68] reported that autogenous grafts had a higher percentage of vital bone at 4 to 6 months than did anorganic bone replacement grafts. However, several histological studies[16,23,69,70] showed that similar percentages of vital bone can be achieved in bone replacement grafts and in grafts with an autogenous component, provided the bone replacement grafts are allowed a longer maturation period. Further, Valentini et al.[23] have reported that residual xenograft in a maturing graft resides in the connective tissue compartment and, when combined with newly formed vital bone, can create a graft of exceptionally high density (i.e., vital bone plus residual mineralized xenograft). Histology of explants from the maxillary sinus do not show residual xenograft particles in con-

* OsteoGraf/N, Dentsply/CeraMed Dental, Lakewood, CO.
† Bio-Oss, OsteoHealth Co., Shirley, NY.

tact with the implant surface, thereby leaving the implant surface free to interface with newly formed vital bone.[71,72]

Implant Surfaces

Statistical differences were apparent when comparing machine-surfaced implants versus all other implant surfaces (i.e., rough or textured titanium surfaces, hydroxyapatite-coated surfaces) with unadjusted mean implant survival rates of 95.2% and 82.4% for rough and machined implants, respectively (Table 7). The data on the effect of implant surface micromorphology on implant survival was evaluated in a covariance model with the type of grafting procedure. When this was done (Table 9), the survival rates of rough surfaced and machine-surfaced implants in particulate grafts become 94.6% and 90.0%, respectively. In iliac block grafts the survival rates for rough surfaced and machine-surfaced implants were 89.5% and 78.8%, respectively.

Membranes

A randomly controlled clinical trial by Tarnow et al.,[13] in which the presence or absence of a barrier membrane was the only variable, reported implant survival rates of 100% and 92.6%, respectively, for grafts with and without membranes. A controlled trial by Tawil et al.[15] reported 93.1% survival in the membrane group and 78.1% in the no-membrane group. Another controlled trial by Froum et al.[16] reported 99.2 % survival in the membrane group and 96.3% when a membrane was not utilized (Table 10). A meta-analysis of these 3 comparative studies (Fig. 1) supports the hypothesis that membrane utilization is a useful adjunctive therapy that results in an increased survival rate (P <0.02) for implants placed in sinus grafts.

In a second analysis implant survival in 5 studies with particulate grafts that utilized a membrane over the lateral window was 93.6% for 919 implants, as compared to 88.7% for 2,436 implants in 15 studies that did not utilize a membrane (Table 11). Again the survival rate for the studies utilizing a membrane (using each study as an N = 1) was significantly better (P<0.05) than for the studies that did not utilize a membrane. The strength of this analysis was increased by the similarity of the survival rates in both the direct comparisons (3 studies)[13,15,16] and in the comparative case series (15 versus 5 studies; Table 11).

The increase in implant survival may be explained by the reported higher percentage of vital bone that results when a membrane is placed over the window. A bilateral RCT with the presence or absence of a membrane over the window being the only variable by Tarnow et al.[13] reported vital bone formation of 25.5% (SD 14.5) when a membrane was utilized and 11.9% (SD 7.9) when a membrane was not placed over the lateral window.

Simultaneous Versus Delayed Implant Placement

As presented in Table 2 for the lateral window technique, there are 12 studies with simultaneous placement, 9 studies with delayed placement, and 13 studies reporting on both techniques. Of those reporting on both techniques, 8 studies separated the data. The implant survival rates for the combined simultaneous placement and delayed placement studies (Table 12) were 89.7% and 89.6%, respectively.

In evaluating these data, one must consider the number of covariables that are present when implant survival data are combined in non-controlled studies. In this case covariables include, but are not limited to, block versus particulate surgery, machined versus rough surface, and presurgical residual crestal bone height. Residual crestal bone height in the included studies varied from 1 to ≥8 mm. The ranges for simultaneous or delayed placements overlap, thus blending the 2 intervention types and their subsequent survival rates. Furthermore, not all studies listed the minimum or range of residual crestal bone heights included in the studies (28 of 34 reported). It is reasonable to consider that the failure rate for delayed implants is influenced by the fact that delayed placement is more likely to be utilized in cases that had lesser height of residual crestal bone as opposed to simultaneous placements that are most likely to have a greater height of residual crestal bone. It should be noted, however, that studies by Peleg et al.[26,36] have reported 100% implant survival in simultaneous placements with 1 to 2 and 3 to 5 mm of crestal bone.

The data available for this review were insufficient to draw statistical conclusions on the effect of residual crestal bone height on implant survival. While 28 of 34 studies reported residual crestal bone height to range from 1 to ≥8 mm, none of the studies recorded the residual crestal height of failed implants.

Residual crestal bone height, as it relates to achieving primary implant stability, is a primary consideration utilized by the clinician in choosing a simultaneous over a delayed implant placement. Primary stability of implants has always been considered as an important factor affecting implant survival. Given similar bone quality, primary stability should be more easily achieved when a greater height of residual crestal bone is present. However, the significance of having a specific amount of residual bone height can be questioned. DePorter et al.[47] showed survival rates for short porous-surfaced implants similar to those reported for standard length implants. Testori et al.[66,67] demonstrated high success rates for short, acid-etched implants in poor quality bone, and Peleg et al.[26] reported 100% implant survival for simultaneous placement of hydroxyapatite-coated implants in sinus grafts with 1 to 2 mm of

crestal bone. This situation highlights the difficulties encountered when attempting to draw conclusions from non-controlled studies due to the presence of multiple confounding variables. The above-mentioned studies all utilized textured or coated implants, while our original paradigms date back to the machine-surfaced implant.

In addition, one must consider the differences that may exist in the percent volume of vital bone available for osseointegration when comparing the residual crestal bone to a matured sinus bone graft. Ulm et al.[73] have reported that mean trabecular bone content by volume in the maxillary molar region may be as low as 6.73% and averages 17.1% in females and 23.4% in males. Trisi and Rao[74] report trabecular bone volume of 28.28% ± 12.02% for bone quality of D4 (Misch classification). Histological studies by Froum et al.[16] and Valentini et al.[23] found vital bone volumes in this range for sinus bone replacement grafts. When this is considered in combination with the observation from sinus explants[71,72] that residual xenograft does not directly contact the implant surface, it could be speculated that osseointegration in these grafts is not hampered by the presence of the xenograft. In fact, the presence of the xenograft might provide additional structural stability to the matured graft that is lacking in grafts of pure autogenous bone and/or demineralized allograft. If this is correct, residual crestal bone height may only be important as it relates to initial mechanical primary stability, protecting the implant from micromovement resulting from inadvertent early loading.

Bone Morphogenetic Proteins and Bone Growth Factors

This review identified one rigorously conducted randomly controlled trial by Boyne et al.[12] that compared, with similar results, recombinant human bone morphogenetic bone (rhBMP-2)/collagen sponge implants to grafts of autogenous bone and composite grafts containing an autogenous component. A retrospective study by Rodriguez et al.[30] utilizing platelet-rich plasma (PRP) with no controls was also identified. This study reported an implant survival rate of 92.9%. This survival rate was lower than the average survival rate of 94.6% for the studies in this review that utilized particulate grafts and rough-surfaced implants without PRP. Histological reports by Froum et al.[75] and Wiltfang et al.[76] have shown only a 5 to 10% increase in vital bone formation when comparing sinus elevations using the same graft material with and without the addition of platelet-rich plasma. Zuffetti et al.[77] in an 8-case split-mouth sinus study utilizing cancellous iliac crest marrow, showed no significant differences in bone maturation level resulting from the use of PRP. A preliminary histomorphometric evaluation by Maiorana et al.[78] of 2 specimens utilizing 100% xenograft† plus PRP at 6 months post-grafting revealed a total bone percent volume (xenograft plus newly formed bone) of just below 40%. Valentini et al.,[23] on the other hand, found a total bone percent volume of 60% for a 1:1 composite of demineralized freeze-dried bone allograft (DFDBA) and the same xenograft in a 6-month time period when utilized without PRP. Sánchez et al.[79] in a recent review concluded that there is a lack of evidence for the utilization of PRP in combination with bone grafts based on the existing studies of small sample size and poor quality, most of which have not shown highly positive outcomes.

REVIEWERS' CONCLUSIONS

Within the limits of this systematic review, the following conclusions can be drawn:

1. The survival rate of implants placed in augmented sinuses varied between 61.7% and 100% with the average survival rate of all interventions being 92.6%.
2. Implant survival rates reported in this systematic review compare favorably to reported survival rates for implants placed in the non-grafted posterior maxilla.
3. Rough-surfaced implants have a higher survival rate than machine-surfaced implants when placed in grafted sinuses.
4. Implants placed in sinuses augmented with particulate grafts show a higher survival rate than those placed in sinuses that had been augmented with block grafts.
5. Implant survival rates were higher when a membrane was placed over the lateral window.
6. The utilization of grafts consisting of 100% autogenous bone or the inclusion of autogenous bone as a component of a composite graft did not affect implant survival.
7. There was no statistical difference between the covariates of simultaneous versus delayed implant placement, types of rough-surfaced implants, length of follow-up, year of publication, and the evidence level of the study.
8. Insufficient data were present to statistically evaluate the effects of smoking, residual crestal bone height, screw versus press-fit implant design, or the effect of implant surface micromorphology other than machined versus rough surfaces.
9. Insufficient evidence exists to recommend the utilization of platelet-rich plasma in sinus graft surgery.

FUTURE DIRECTIONS

Further research is needed to determine the effect of residual crestal bone height and smoking on implant survival. Additionally, more data are required to determine the efficacy of bone morphogenetic proteins and bone growth factors on bone formation and implant survival in the maxillary sinus.

Controlled trials that limit the variables to the one that is being evaluated are required to properly identify and

isolate the effects of what, to date, must be considered multiple confounding variables.

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APPENDIX A
CONSENSUS REPORT

Members of the Section read and studied the review titled "Effect of Maxillary Sinus Augmentation on the Survival of Endosseous Dental Implants. A Systematic Review," by Stephen S. Wallace and Stuart J. Froum. The focused PICO question addressed by this evidence-based systematic review is: "In patients requiring dental implant placement, what is the effect on implant survival of maxillary sinus augmentation versus implant placement in the non-grafted posterior maxilla?"

INTRODUCTION

This sinus bone augmentation Consensus Report represents a collaborative effort of all Section participants. The primary reviewer presented his data for each of the 5 questions. Section participants then expressed their concerns and suggestions which, in many cases, resulted in modifications to the consensus statements. The process was repeated until final consensus was achieved.

It was the consensus of all members of the Section that sufficient evidence was available to make the definitive statements presented in this report.

1. Does the Section agree that the evidence-based systematic review is complete and accurate?

Yes. The Section members found that the reviewers were thorough and complete in assimilating a systematic review of evidence-based data for sinus bone augmentation. The following information should be noted.

While there was ample evidence to support the lateral wall approach for sinus bone augmentation, the studies on alternative techniques (e.g., osteotome, localized management of the sinus floor, crestal core elevation) for sinus bone augmentation are limited in number and no conclusions relating to implant survival rate can be drawn at this time.

2. Has any new information been generated or discovered since the evidence-based search cut-off date?

Yes, 2 additional publications that provide supportive information have been identified:

A recent evidence-based review on the lateral wall approach for sinus bone augmentation by Del Fabbro et al.[1] determined an overall implant survival rate that was similar to that found with this review.

A recent study found no deleterious effects on voice quality and sinus physiology following sinus bone augmentation procedures.[2]

3. Does the Section agree with the interpretations and conclusions of the reviewers?

The Section participants found the interpretations and conclusions of the reviewers thorough and accurate.

4. What further research needs to be done relative to the focused questions of the evidence-based review?
The following studies were identified by the Section as areas for further research to individually evaluate the success of sinus bone augmentation and the success of implants placed in the augmented sinus.

Due to concerns regarding the limited data specifically evaluating the variable of residual crestal bone height, a research project is recommended for evaluating the success rate of implants as it relates specifically to minimal crestal bone height. These studies should ideally use a bilateral sinus model.

While no absolute contraindications exist in the literature, it would be beneficial to evaluate implant success as it relates to potential risk factors such as Schneiderian membrane perforations, initial implant stability, postoperative sinus infections, smoking, periodontal disease, sinus pathology, and other systemic and behavioral factors.

Studies are warranted to evaluate tissue-engineering techniques (e.g., molecular, cellular, and genetic) that may reduce the time required prior to prosthesis delivery and may enhance bone quality and quantity. These studies ideally should use a bilateral sinus model.

Further studies to evaluate the efficacy of alternative sinus bone augmentation techniques are recommended, due to the limited number of studies on these alternative techniques (e.g., osteotome, localized management of the sinus floor, crestal core elevation).

5. How can the information from the evidence-based review be applied to patient management?
A. There is evidence to indicate that the lateral window technique for the sinus bone augmentation procedure is successful at regenerating sufficient bone for implant placement. The implant survival rate is greater than 90%, which is similar to implants placed in native bone.

Level of Evidence:[3] Strong.

Rationale: Assignment of this level of evidence is based on 3 level I, 4 level II-1, 11 level II-2, and 16 level II-3 studies. These 34 studies included 5,267 implants thus providing a well-founded estimate of the survival rate.

B. There is evidence that the following factors, when adjusted for other variables, increase implant survival when performing lateral wall sinus bone augmentation procedures:

Membrane coverage (93.6% survival) and no membrane coverage (88.7% survival) of the lateral window. The forest plot (Fig. 1) in the systematic review paper indicates statistical significance ($P = 0.019$).

Level of Evidence: Strong.

Rationale: Assignment of this level of evidence is based on 1 level I, 2 level II-1, 8 level II-2, and 12 level II-3 studies.

Particulate bone grafts (92.3% survival) rather than block grafts (83.3% survival). These percentages (least square means) were adjusted for other variables as determined by meta-regression.

Level of Evidence: Moderate.

Rationale: Assignment of this level of evidence is based on 3 level I, 4 level II-1, 10 level II-2, and 12 level II-3 studies.

Rough (94.6% survival) surfaces and machined (90.0% survival) surfaces for the implants. These percentages (least square means) were adjusted for other variables as determined by meta-regression.

Level of Evidence: Moderate.

Rationale: Assignment of this level of evidence is based on 1 level I, 2 level II-1, 7 level II-2, and 12 level II-3 studies.

C. There is insufficient evidence to support the use of platelet-rich plasma (PRP) in lateral wall sinus bone augmentation.

Level of Evidence: Insufficient.

Rationale: Assignment of this level of evidence is based on 1 level II-3 study, 8 histomorphometric studies, and 1 review.

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